DEPTH

OF

EVAPORATION

IN THE

UNITED STATES.

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DEPTH OF EVAPORATION IN THE UNITED STATES.

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It has been proposed to find the depth of evaporation that takes place inside the thermometer shelters at the various Signal Service stations. For this purpose the relation has been determined between the evaporation observed at a few stations with Piche evaporometers and the condition of the air as to dryness, deduced from the tri-daily readings of the whirled, wet, and dry-bulb thermometers. The relation between the evaporation as given by a Piche instrument, and what it would be from a water surface, has been determined by comparisons at the Signal Office in Washington of the amounts of evaporation from the Piche with that from a cylindrical tin vessel 6.55 centimetres in diameter and 1.3 centimetres in depth, filled to the brim with water. The amounts of evaporation were obtained by weighings on successive days made to the nearest hundredth of a gramme by means of a fine balance.

The results of the determinations of the evaporation for the whole country are contained in Table III, which gives the computed depth in inches for each month and year. The chart, No. vi, is based on this table. The lines join places having equal annual depth of evaporation.

It is believed that these figures represent, approximately, the evaporation that takes place from the surface of ponds, rivers, reservoirs, and lakes in the vicinity of the Signal Service stations.

This belief is based principally on the results of observations of evaporation and determinations of the humidity of the air from wet and dry-bulb thermometer readings made at Nukuss, from May to October, 1875, under the direction of the Central Physical Observatory at St. Petersburg, and reported upon by Ed. Stelling in Band viii, No. 3, of Wild's "Repertorium für Meteorlogie," 1882.

The observations were made by weighings of the evaporation from the surface of a pond by means of a vessel containing water immersed in the pond. Observations were also made of the evaporation from a water vessel on land, exposed in the sunshine, and from a similar vessel in a thermometer shelter. The wet and dry-bulb thermometers were read every two hours throughout the day during the whole time for five months that the evaporation observations were made. The results of the work were, as given by Stelling, that the humidity results, obtained from wet and dry-bulb readings with suitable constants, represented the evaporation from the surface of the pond within 15 per cent., and that the evaporation from the vessel in the sunshine for the average of five months was about 10 per cent. greater than that from the vessel in shelter. For one month, however—September—the evaporation in the shelter was about 3 per cent. greater than that in sunshine. The air is very dry at Nukuss. The depth of evaporation in June, in the sunshine, the greatest in five months, was 14.9 inches.

Observations of evaporation in Signal Service shelters, from water dishes, would be very difficult. There are many difficulties in the way of observing evaporation from water dishes in the open air. The falling of rain splashes the water from the vessel or adds to it. When the temperature of the air is below freezing it is impossible to get a fair measure of evaporation for a great part of the time, on account of the drifting snow. For the winter season the evaporation calculated by an empirical process from the dryness of the air, such as has been used here for the whole year round, is probably more accurate than any results of direct measurement.

It is acknowledged that the results of direct measurement of evaporation from water dishes, by weighing, would, on the whole, give a more satisfactory determination of the depth of evaporation than the process here resorted to, but the expense of procuring balances, and the great labor entailed on the men at stations by the method, forbid its use.

Even after evaporation is obtained from dishes it is doubtful what it represents. Under the same circumstances of temperature and dryness of air, different shaped vessels will give different results for the depth of evaporation, presumably on account of the varying facility with which the vessel takes the temperature of the air, which depends on its shape, the material of which it is made, and its absolute size. A cylindrical vessel of the same bulk as a rectangular one exposes less surface to the air, and as the vessel gains its heat by contact with the air, it will usually not be at the same temperature as the rectangular one. Evaporation from the surface tends to lower the temperature, and the amount of lowering depends on the relation between the surface and the volume of water. At 8 p. m., as observed at

Nukuss, this lowering of the temperature of the water in vessels amounted, on the average in June, to 9°.9 Fahr.

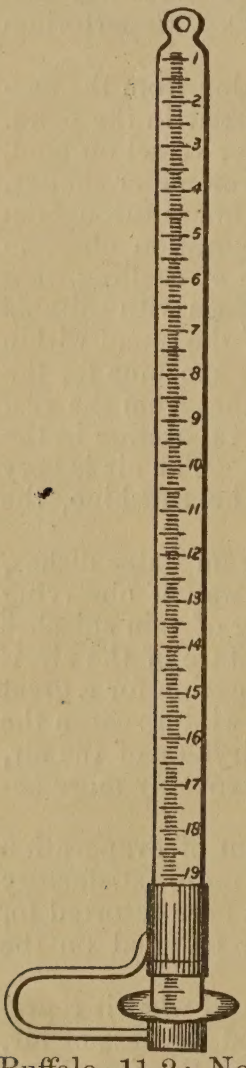
But greater than all other things, in its effects on the depth of evaporation from vessels, is the effect of the depth of the water surface below the rim of the vessel. In the case of a vessel of circular section 2.5 inches in diameter, the evaporation, when brimfull, is about 50 per cent. greater than when the water surface is 0.3 of an inch below the rim.

Even if a satisfactory size and shape of vessel for observation of evaporation could be settled upon, it is very doubtful how nearly evaporation from it would represent the actual evaporation from the surface of a neighboring pond or river, owing to the uncertainty of the effect of the wind. Wind promotes evaporation powerfully, as will be seen further on. But, by means of wind velocities, as measured by anemometers high up in the air, it is hard to estimate the effects of wind on evaporation from a pond or river sheltered by trees or high banks.

For any particular place the most satisfactory way to obtain the depth of evaporation would be by a special investigation for that place.

The Piche evaporometer (see figure) consists of a glass tube 9 inches long and 0.4 of an inch internal diameter. The top end is closed and has an eye for suspending the instrument. The tube is filled with water and on the open end a paper disk 1.2 of an inch in diameter is placed and held in position by a brass fixture sliding easily in a collar along the tube. Water is supplied to the paper from the tube by capillary action, and evaporates freely from it into the air, the amount depending on the dryness of the air and the velocity of the wind. There is a scale etched on the tube to cubic centimetres and tenths. The difference in the readings of the top of the column of water gives the volume evaporated from the paper in the interval between the readings.

Figure.



Twenty-five of these instruments were procured for the Signal Service, and observations were made daily with eighteen of them at various stations, from the 31st of May to the 30th of September, 1888.

A few of the instruments were calibrated with mercury to test their graduation and were found to be very exact, except in the case of the one sent to Yuma, which was discovered by the observer to be graduated incorrectly below 17 cubic centimetres by one whole cubic centimetre. The paper disks supplied to the stations were all exactly of the same diameter, and the paper all of the same kind, thin, not over one hundredth of an inch thick, and unsized. The brass circular disks holding the paper in place on the tube were all measured and found to have the same diameter within one-tenth of a millimetre. The external diameters of the tubes, where in contact with the paper, varied from 14.0 millimetres to 15.6. The amount of paper surface exposed to the air was taken as twice the area of the paper disk, minus the area of the end of tube, minus the area of brass disk. The amount of surface exposed by the edge of the paper was neglected. Even if this surface was appreciable it is allowed for by the method of standardizing the evaporometers by reference to the water dishes.

The amount of paper surface exposed in the various evaporometers varied from 11.0 square centimetres to 11.4, as follows:

Nos. 1, 2, 3, 6, and 14, at Washington, 11.0, 11.2, 11.2, 11.3, and 11.2, respectively; No. 4 at Boston, 11.2; No. 5 at New York, 11.2; No. 7 at Charlotte, 11.4; No. 8 at Buffalo, 11.2; No. 9 at Cincinnati, 11.2; No. 10 at Memphis, 11.2; No. 11 at New Orleans, 11.3; No. 12 at Chicago, 11.2; No. 13 at Saint Louis, 11.4; No. 15 at Keeler, 11.2; No. 16 at Yuma, 11.2; No. 17 at El Paso, 11.0; No. 18 at Dodge City, 11.2; No. 19 at San Antonio, 11.2; No. 20 at Omaha, 11.2; No. 21 at Denver, 11.2; No. 22 at Saint Vincent, 11.2; No. 23 at Helena, 11.4; No. 24 at Boisé City, 11.3.

The instrument at Charlotte was broken before any observations were obtained. The observations were not well started at Buffalo until the middle of August.

These instruments were mounted in the thermometer shelters at the stations. They were read once a day at 10 p. m. during June, and at 8 p. m. during July, August, and September. The difference in the readings on successive days gave the amount of evaporation for the various days.

The shelters on Signal Service stations are usually at a height of nine feet above the roof of building where situated. The shelter is a cubical box three feet on a side, with the sides of open louvre or lattice work, and a close board bottom and a close double top. It opens by a hinged louvre-work door to the north, which is kept closed except while observations are being made.

To determine the relation between the evaporation from a water surface and that from the Piche, two Piches were compared, in the quiet air of a closed room, with two tin dish-evaporometers, each 6.55 centimetres in diameter and 1.3 in depth. In these experiments the Piches were weighed from day to day, as well as the dishes, and not read by the etched scales, as was the case with those on stations.

The results of the experiments showed that the rate of evaporation from the dishes diminished regularly as its water surface fell below the edge of the vessel. The Piches evaporated 1.33 times that of the dishes, surface for surface, as compared with the dishes while quite full. The coefficient increased to 2.05 as the surface of the water in dish fell.

The coefficient used to reduce the Piche evaporations on stations to an equivalent water surface was 1.33. This was the mean obtained from all the observations with the vessels quite full, as long as the water surfaces did not fall more than 1.5 of a milimetre below the edges of the vessels. All other observations with the surfaces below this limit were rejected.

The coefficient of a similar instrument, as determined by Prof. M. Kunze by comparison with evaporation from a metal dish with a surface of 250 square centimetres (about eight times that of the above), was found to be 1.42, as given by the mean of comparisons from April to October, 1880. The results of the observations are contained in Band xvi of the "Zeitschrift für Meteorolgie," 1881, on page 31.

Dr. Riegler, in Band xiv of the "Zeitschrift" for 1879, page 373, gives the coefficient of Piche as 2.03. His results for the coefficient, which vary all the way from 1.64 to 2.22, are no doubt due to the varying depth of water surface below the edge of evaporating vessel. The vessel used in this case was a 1½ litre cylindrical thin glass vessel immersed in a basin of water exposed in a garden, and weighed at intervals of a few days when there had been no rainfall during the interval.

Concerning the effect of varying kinds of paper used on the Piche, Dr. Riegler says: "Comparative observations showed that papers of perceptibly different thicknesses to the naked eye, and even well marked variations in superficial appearance, gave no perceptible variation in the amount of evaporation provided the paper was unsized." The writers experience also agrees with this. A pad of the thickest sort of blotting paper was cut to exactly the size of the disks in use, and the evaporation from it was found to exceed the other only in the proportion of 107 to 100. The blotting paper being thick, exposed more edge surface than the other disks.

Different Piches, when read together, were found to agree very closely with each other, much more so than two similar tin dishes.

The height of water in the tube, whether full or only containing a small quantity of water, makes no appreciable difference in the rate of evaporation, as was ascertained by experiment.

The following series of results shows what may be expected in the way of agreement among different instruments:

Depth of evaporation, in milimetres, in quiet air.

Date.	Dish A.	Dish B.	Piche No. 2.	Piche No. 3.	Coefficients.	
					No. 2.	No. 3.
1888.						
June 27 to 28	1.03	1.03	1.36	1.38	1.32	1.34
June 28 to 29	1.04	1.01	1.45	1.46	1.41	1.42
June 29 to 30	0.80	0.83	1.37	1.41	1.67	1.72
June 30 to July 1	0.70	0.76	1.32	1.35	1.82	1.85
July 1 to July 2	0.89	0.96	1.66	1.72	1.79	1.86
July 2 to July 3	0.89	....	1.79	1.86	2.01	2.09

The increasing coefficient, as previously stated, is due to the fall of water surface below edge of vessel.

In Table I are given the depths of evaporation observed with the Piche instruments on stations, reduced by the coefficient 1.33.

TABLE I.—*Depth of evaporation, in inches, observed with Piche instruments, and average wind velocities, in miles per hour.*

Station.	June, 1888.		July, 1888.		August, 1888.		Sept., 1888.	
	Inches.	Miles.	Inches.	Miles.	Inches.	Miles.	Inches.	Miles.
Boston	5.16	10.2	5.87	10.8	5.28	11.3	2.68	9.6
New York	4.49	8.3	5.36	8.4	4.14	9.0	2.88	8.2
Washington	4.64	4.8	4.27	4.5	4.22	3.9	2.52	4.4
Buffalo	....	....	....	....	....	....	3.70	8.1
Cincinnati	6.22	6.1	6.93	5.7	5.36	5.6	4.33	6.4
Memphis	4.33	4.8	5.24	3.9	4.57	5.4	3.86	5.1
New Orleans	3.82	6.8	9.38	6.0	7.96	8.0	3.70	6.3
Chicago	5.59	10.3	5.52	8.7	6.97	10.4	5.79	9.3
Saint Louis	6.18	9.7	5.79	7.9	4.41	8.2	4.61	8.6
Keeler	11.66	7.9	12.76	6.8	12.69	5.4	10.95	6.0
Yuma	13.87	7.3	13.63	7.2	12.88	5.9	10.36	5.4
El Paso	13.91	8.2	9.89	7.2	11.54	8.0	10.00	5.4
Dodge City	7.80	11.6	8.20	12.0	6.22	9.8	6.07	....
San Antonio	2.76	8.1	5.08	7.1	5.36	7.7	3.66	5.8
Omaha	7.01	7.6	6.62	7.0	5.44	6.8	6.78	7.3
Denver	9.42	8.0	10.91	6.7	8.55	6.2	5.94	....
Saint Vincent	5.63	7.6	4.33	7.4	4.97	7.5	....	9.4
Helena	4.88	7.9	8.20	7.1	7.80	6.2	6.86	6.7
Boisé City*	5.83	3.1	9.14	2.2	7.68	1.5	....	2.6

*Boisé City, October, 7.60 inches.

The amount of evaporation depends principally on the dryness of the air and the velocity of the wind blowing over the evaporating surface. The measure of the dryness of the air is the difference in vapor tension corresponding to the temperature of the air and that corresponding to the temperature of the dew-point.

The wind prevailing inside the shelters is much less than that outside shown by the anemometers. These latter are the ones given in table above.

At Washington City, in the shelter at new office (not the same one as that in which evaporation above given was observed) the wind velocity, by an anemometer set up inside the shelter for eight days, gave a result of 3.48 miles an hour as compared with a velocity of 6.63 miles outside, only 52 per cent. of the velocity outside.

It has been found impossible to make any satisfactory allowance for the wind effect varying with velocity in the observations of evaporation given here, on account of the interference with the wind produced by the sides of the shelter.

Stelling represents the evaporation as the sum of two products, one a constant multiplied by the difference of vapor tension corresponding to the temperature of the water in vessel, and the tension for temperature of dew-point of the air the other factor; the other product a constant multiplied by the wind velocity and the same differences of vapor tensions. While this may be satisfactory for the open air, it does not seem to work well when applied to observations in a shelter. The wind effect has been therefore left out of consideration in this work, except in as far as its effect at all places is taken to be uniform. The figures here given for depth of evaporation must be viewed as applying for the average state of the wind, which, all the year round at stations of the Signal Service does not, on the average, amount to more than 8.5 miles per hour.

A scrutiny of the results of evaporation for single days at the various stations shows it to depend more largely on the dryness of the air than the wind travel for the day.

Experiments were made which show that the effect of the wind on the evaporation from a vessel exposed in the open air is very great. Two Piche instruments were taken, one suspended in quiet air and the other fixed rigidly on the end of the 28-foot arm of the whirling machine set up in the enclosure of the Pension Office building. The whirling machine was the one used in standardizing anemometers. The instruments, filled with water, were first

weighed on a fine balance to the hundredth of a gramme. The whirling arm was then turned so that the Piche on its end moved with a velocity of five miles an hour. The motion was continued for half an hour, and at the end of the time both Piches were again weighed. Then, the Piche that had been suspended in quiet air was put on the arm, and the one that had been on the arm was put in its place. The whirling was then started again at the same velocity, and continued for another half hour. At the end of the time the Piches were again weighed. While this was being done the humidity of the air was determined from time to time by means of whirled wet and dry-bulb thermometers.

Observations were also made in the same way with the Piche moving at velocities of 10, 15, 20, 25, and 30 miles per hour. At a velocity of 5 miles an hour the evaporation from a Piche was 2.2 times that from one in quiet air; at 10 miles, 3.8 times; at 15 miles, 4.9 times; at 20 miles, 5.7 times; at 25 miles, 6.1 times; and at 30 miles, 6.3 times. During the time the observations were made, June 25 and 26, 1888, the average temperature of the air was 83.7, and the relative humidity 50 per cent.

The effect of barometric pressure on evaporation, other things being equal, is to cause the evaporation to be greater as the pressure is lower. The energy required in the expansion of a gas, or the development of a vapor, is equal to the product of the pressure by the volume of vapor produced. The energy remaining the same, then the amount of vapor developed will be inversely proportional to the pressure. The energy required in evaporation comes from the heat of the water, and the water derives its heat, in turn, from the surrounding air by contact of the air-particles with the vessel. The power of the air to communicate heat to the vessel will, of course, be less as its pressure is greater; but it is not imagined that there would be any appreciable diminution of its heat-communicating capacity for pressures only 4 or 5 inches below 30 inches. In the work here, therefore, the evaporation at a place with a pressure below 30 inches is taken to be greater than it would be if the pressure were 30, in the proportion of 30 divided by the pressure at the place.

In Table II are given for the month of June, at the stations where Piche evaporometers were observed, the mean dew-point and the mean air temperature and the mean wet-bulb thermometer readings, as derived from the tri-daily observations made at 7 a. m., 3 p. m., and 10 p. m. Table II also contains the mean barometer readings, the vapor tension corresponding to wet-bulb temperature and the dew point, and the Pichè evaporation reduced by the barometer factor, as explained above.

TABLE II.—*Temperature, wet-bulb, dew-point, vapor-tension, barometric pressure, and reduced evaporation, June,* 1888.

Stations.	Mean temperature.	Meen wet-bulb.	Mean vapor tension.	Mean dew-point.	Mean vapor tension.	Mean barometer.	Reduced evaporation.
	°	°	*Inches.*	°	*Inches.*	*Inches.*	*Inches.*
Boston	66.8	59.7	.512	54.7	.427	29.8	5.11
New York	71.4	64.1	.597	60.1	.519	29.7	4.44
Washington	73.0	65.7	.631	61.8	.551	29.8	4.60
Cincinnati	74.2	64.1	.597	57.8	.478	29.3	6.04
Memphis	75.4	68.7	.700	65.3	.623	29.6	4.29
New Orleans	77.3	72.1	.786	69.8	.727	29.9	3.79
Chicago	67.4	60.0	.517	54.9	.430	29.2	5.43
Saint Louis	73.2	66.2	.643	62.2	.559	29.3	6.00
Keeler	73.9	54.3	.421	33.6	.192	26.2	10.14
Yuma	85.6	62.8	.571	46.0	.310	29.6	13.73
El Paso	83.0	60.7	.529	42.5	.271	26.1	12.10
Dodge City	74.5	63.2	.579	56.2	.451	27.3	7.11
San Antonio	78.0	72.2	.789	69.6	.722	29.1	2.68
Omaha	70.0	62.1	.557	56.9	.463	28.7	6.68
Denver	68.4	52.8	.399	36.8	.218	24.7	7.79
Saint Vincent	62.8	57.1	.466	52.7	.397	28.9	5.41
Helena	58.8	50.7	.369	43.4	.281	25.7	4.17
Boisé City	64.2	53.6	.411	44.5	.293	27.0	5.20

The readings of the dry and wet-bulb thermometers at the Signal Service stations are made on a uniform plan. They are whirled inside the thermometer shelters on a whirling apparatus provided for the purpose. The computations

of dew-point are also uniform and are made from tables based on an extensive series of comparative observations between a Regnault dew-point apparatus and whirled wet and dry-bulb thermometers made at varying temperatures and humidities at Washington City, Colorado Springs, and the top of Pike's Peak. The vapor tensions for temperature, taken as the basis of the tables used, are Broch's values given in Memoirs of Int. Bur., Vol. I, derived from a re-reduction of Regnault's observed values for the tensions.

All the wet and dry-bulb thermometers at stations have cylindrical bulbs. These instruments have all been supplied to stations within two years past and are all of a high order of excellence. They are stem-graduated to single degrees and the tubes were a number of years old before being graduated, so as to provide to some extent against changes of their freezing points with age. Before issue to stations they were compared at Washington City with standards at temperatures from —28° to 102°. No thermometer is issued which has a correction at any of the points ten degrees apart as great as 0°.3, except in rare instances. In nine-tenths of the cases the corrections are not as large as 0°.1. No corrections are applied on stations unless they are 0°.3 or more. The whirling of the thermometers gives a satisfactory determination for the dew-point even when the temperature of the wet-bulb is below 32°.

The Signal Service thermometer readings and the humidity of the air calculated from them have a high degree of accuracy on account of the excellence of the instruments and their exposure. These circumstances are mentioned because results for humidity of air derived from inaccurate instruments are of little value, as even the smallest errors of instruments enter the determination of vapor tensions from wet and dry-bulb thermometers with great effect.

The amount of evaporation that takes place depends on the dryness of the air, the wind velocity, and the temperature of the evaporating water. In the case of the Piche evaporometer the temperature of the evaporating water is strictly that of a wet-bulb thermometer exposed at the same place.

For the purpose of deriving constants to establish the relation between the amount of evaporation and the dryness of the air, the evaporation will be taken as dependent on the difference of the vapor tensions at dew-point and the temperature of the wet-bulb multiplied by a constant, and on the vapor tension corresponding to the temperature of the wet-bulb multiplied by another constant.

For the various stations where Piches were observed the observation equations given below were formed in this way: The absolute term of each equation is the depth of evaporation at each place, reduced for the barometric pressure as previously explained. Giving these equations equal weight and treating them according to the method of least squares, in the usual manner, multiplying each one through by the coefficient of A, in that equation, and adding, then multiplying each by its coefficient of B, and adding, two normal equations are obtained. Solving these, the values of A and B are derived, which, substituted in the original equations, give the residuals.

Observation equations, residuals	(comp.-obs.).	
+.512 A +.058 B — 5.11 = v.	— .38	Boston.
+.597 A +.078 B — 4.44 = v.	+ .15	New York.
+.631 A +.080 B — 4.60 = v.	+ .15	Washington.
+.597 A +.119 B — 6.04 = v.	+ .35	Cincinnati.
+.700 A +.077 B — 4.29 = v.	+ .46	Memphis.
+.786 A +.059 B — 3.79 = v.	+ .34	New Orleans.
+.517 A +.087 B — 5.43 = v.	— .60	Chicago.
+.643 A +.084 B — 6.00 = v.	—1.05	Saint Louis.
+.421 A +.229 B —10.14 = v.	+ .73	Keeler.
+.571 A +.261 B —13.73 = v.	—1.15	Yuma.
+.529 A +.258 B —12.10 = v.	+ .27	El Paso.
+.579 A +.128 B — 7.11 = v.	— .36	Dodge City.
+.789 A +.067 B — 2.68 = v.	+1.81	San Antonio.
+.557 A +.094 B — 6.68 = v.	—1.46	Omaha.
+.399 A +.181 B — 7.79 = v.	+ .94	Denver.
+.466 A +.069 B — 5,41 = v.	—1.47	Saint Vincent.
+.369 A +.088 B — 4.17 = v.	+ .41	Helena.
+.411 A +.118 B — 5.20 = v.	+ .79	Boisé City.

Normal equations:

$$(5.887)\,A + 1.1550\,B - 62.21 = 0 \qquad A = 1.96.$$
$$1.1550\,A + (0.3337)\,B - 16.90 = 0 \qquad B = 43.88.$$

These residuals are quite satisfactory, very much more so than any set that can be derived by allowing for a variable wind effect according to the velocities given in Table I.

Constants have not been computed by means of the Piche evaporation observations made in July, August, and September, as there was a change in the hours of observation of thermometers beginning with July, the thermometers being read at 8 a. m. and 8 p. m., instead of 7 a. m., 3 p. m., and 10 p. m., as formerly. An observation has been made at 3 p. m., and it is to be continued until the end of the present year, but it has not been reduced and carried into the regular forms. To get the mean wet-bulb temperatures and dew-points including this observation, the original records would have to be consulted. The labor of forming means, etc., would have been so great that it was not undertaken.

The evaporation for July to December, 1887, and January to July, 1888. given in Table III, have been computed by the formula—

$$30\left(\frac{A\,p_w + B\,(p_w - p_d)}{b}\right)$$

p_w is the vapor tension corresponding to the monthly mean of the wet-bulb thermometer; p_d is the vapor tension corresponding to the monthly mean dew-point; b is the mean barometer reading; A is a constant equal to 1.96, and B, a constant equal to 43.9. The quantities obtained from the above formula have been multiplied by a factor 1.03 for months of thirty-one days and divided by 1.03 for February. These latter are the quantities given in the table, and they represent evaporations inside of the shelters when the velocity of the wind outside is 7.1 miles per hour. This is the mean of the velocities at the stations during June where the Piches were observed. This probably corresponds to a velocity inside the shelter of 3.5 miles per hour.

The results derived in this way for Boston can be compared with a very elaborate series of observations of evaporation made at the reservoir of the Boston waterworks by Mr Fitzgerald, and reported upon in the Transactions of the American Society of Civil Engineers, Vol. XV, 1886. These observations were made by measuring the evaporation from a large vessel filled with water and immersed in the reservoir. A raft was floated in the reservoir centre for the purpose of making the observations. Mr. Fitzgerald concludes from his experimental work that there was no difference in the amount of evaporation from vessels in sunshine and shade. The results of the work, as given below, are for a different year from that in which the Signal Service observations were made.

Depth of evaporation at Boston.

At the water-works reservoir.		At the Signal Service station.	
Month.	Inches.	Inches.	
January	0.90	1.62	Computed 1888.
February	1.20	1.81	Do.
March	1.80	2.25	Do.
April	3.10	3.22	Do.
May	4.61	4.46	Do.
June	5.86	5.16	Piche observed, 1888.
July	6.28	5.87	Piche observed, 1888.
August	5.49	5.28	Piche observed, 1888.
September	4.09	2.68	Piche observed, 1888.
October	2.95	2.65	Computed, 1887.
November	1.63	2.21	Do.
December	1.20	1.46	Do.
Year	39.11	38.67	
		34.40	July, 1887, to July, 1888.

The mean annual evaporation at the Croton waterworks reservoir, New York, quoted by Mr. Fitzgerald, is 39.21 inches. The evaporation at New York City Signal Service station, as found here, is 40.6 inches.

An extensive series of evaporation experiments was made at Milwaukee in 1862, 1863, and 1864, from April to October. They are given in detail for each day in the Report of the Chief of Engineers for 1867. The results for the months are given below with the evaporations alongside of them as observed

at Chicago by means of the Piche evaporometer in 1888. The Milwaukee observations were made by weighings of a large shallow vessel filled with water and set up inside a thermometer shelter. The incomplete observations, twenty-six days, twenty-seven days, etc., are probably due to loss of the observations caused by rain.

Depth of evaporation in inches.

Month.	Milwaukee. 1862.	Milwaukee. 1863.	Milwaukee. 1864.	Mean.	Chicago, 1888. Piche.
April	....	3.04	2.65	2.84	....
May	4.32 (27)	3.50	8.16 (29)	3.33	....
June	5.54	5.41	7.35	6.10	5.59
July	6.49	5.18	7.45	6.37	5.52
August	5.04	4.73	4.78	4.85	6.97
September	3.83 (27)	4.00	2.00	3.28	5.79
October	3.06	....	....	3.06	....

As regards the accuracy with which the figures for evaporation given in Table III represent the actual evaporation from ponds, rivers, and lakes, the following may be remarked:

The effect of the high exposure of the shelters is to make the figures too great, the wind action being far greater at the height of the shelters than the level of the ground. The evaporation taking place from a small paper disk, as in the results obtained with the Piche instrument have a tendency to be too small, as the determining temperature of evaporation is that of a wet-bulb thermometer exposed under similar circumstances. In the case of a body of water the determining temperature of evaporation is nearly that of the average temperature of the air. In the sunshine it is far above the air temperature in the case of shallow water. The results are probably within 20 per cent. of the truth.

In conclusion it must be stated that these figures only represent possibilities of evaporation and not actual evaporation over the whole surface of the country. If a set of figures were prepared for the various parts of the country which would represent the opportunities of evaporation which depend on the relative amount of land and water surface and on the wetness or dryness of soil and the amount and character of vegetation, the product of the two sets of figures would be the absolute evaporation.

TABLE III.—*Depth of evaporation, in inches, at Signal Service stations, in thermometer shelters, computed from the means of the tri-daily determinations of dew-point and wet-bulb observations.*

Stations and districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
New England.													
Eastport	0.9	1.4	1.5	2.4	2.5	2.7	2.2	2.9	2.5	2.6	2.2	1.4	25.2
Portland	1.0	1.2	1.8	2.6	1.8	3.3	3.8	3.9	3.4	3.0	2.5	1.4	29.7
Manchester	0.9	1.6	2.2	3.3	3.8	5.0	4.1	3.3	2.5	2.8	2.4	1.4	33.3
Northfield	0.8	1.0	1.5	2.3	2.5	3.4	3.5	2.7	2.3	1.8	1.1	1.0	23.9
Boston	1.2	1.6	2.2	3.4	3.1	4.7	4.4	4.0	3.5	2.7	2.2	1.4	34.4
Nantucket	1.1	1.1	1.2	1.5	1.8	2.1	3.3	3.8	3.4	2.7	1.8	1.8	25.6
Wood's Holl	0.5	0.8	1.8	2.4	1.8	2.7	2.7	2.4	2.7	1.2	0.8	0.5	20.3
Block Island	1.1	1.1	1.2	2.0	1.8	2.6	2.5	3.1	2.8	2.6	1.8	1.4	24.0
New Haven	1.1	1.6	1.8	2.7	2.7	4.1	3.7	3.8	3.1	3.2	2.4	1.6	31.8
New London	1.5	1.3	1.5	2.6	2.8	4.0	3.4	3.9	3.2	3.1	2.4	2.1	31.8
Mid. Atlantic States.													
Albany	0.9	1.2	1.6	3.3	3.9	4.5	5.0	4.7	3.2	3.0	2.1	1.4	34.8
New York City	1.8	1.4	2.0	3.4	3.3	4.6	5.0	5.2	4.3	4.1	3.3	2.2	40.6
Philadelphia	1.6	2.1	2.5	4.4	4.0	5.7	5.7	5.2	4.3	4.0	3.3	2.2	45.0
Atlantic City	1.2	1.6	1.5	2.4	1.8	3.6	2.9	3.3	2.4	1.8	1.2	1.5	25.2
Baltimore	2.0	2.2	2.8	5.1	4.7	5.6	6.0	5.0	4.4	4.3	3.6	2.4	48.1
Washington City	1.8	1.7	2.5	4.2	3.8	6.0	5.4	4.9	4.1	4.2	4.5	2.5	45.6
Lynchburg	2.6	2.7	3.4	5.2	4.5	5.6	4.7	4.3	3.3	3.4	3.2	2.6	45.5
Norfolk	1.8	1.6	2.3	3.5	3.2	4.2	4.6	3.7	3.7	2.9	2.3	1.8	35.6
South Atlantic States.													
Charlotte	2.6	2.6	4.3	6.4	4.5	5.8	4.0	4.0	4.6	4.0	3.6	2.6	49.0
Hatteras	1.8	1.6	1.6	2.5	2.2	3.0	3.3	4.1	3.8	3.2	2.6	1.6	31.3
Raleigh	2.0	1.8	2.6	3.8	4.1	5.4	4.2	3.2	3.0	2.7	2.4	1.8	37.0
Wilmington	2.4	2.2	2.7	3.3	3.3	4.3	4.3	3.1	3.9	3.4	2.8	2.7	38.4

TABLE III.—*Depth of evaporation, in inches, at Signal Service stations, &c.*—Continued.

Stations and districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
South Atlantic States.													
Charleston	2.5	2.5	3.5	3.7	3.9	4.4	4.5	4.8	4.2	4.0	3.2	2.5	43.7
Columbia	2.2	2.3	2.6	4.8	4.3	5.4	4.2	3.8	4.2	3.4	3.6	2.4	43.2
Augusta	3.0	2.6	3.4	5.3	4.8	5.0	4.8	4.5	5.1	4.1	3.6	3.1	49.3
Savannah	3.3	2.8	4.1	4.7	4.3	4.6	4.2	4.7	3.4	3.6	3.5	2.8	46.0
Jacksonville	2.9	2.6	3.8	4.3	4.6	5.3	5.0	4.7	3.8	3.6	3.0	2.1	45.7
Florida Peninsula.													
Titusville	3.5	2.6	3.3	3.8	3.8	4.3	3.8	4.3	4.0	4.1	3.6	3.1	44.2
Cedar Keys	3.3	2.8	4.0	4.6	4.5	5.1	5.0	5.5	4.5	4.1	3.5	2.6	49.5
Key West	3.8	3.7	3.8	4.5	4.4	4.8	5.1	5.1	4.7	4.3	3.8	3.6	51.6
Eastern Gulf States.													
Atlanta	2.7	2.6	4.0	6.2	4.7	5.0	4.5	4.7	5.8	4.6	4.2	2.5	51.5
Pensacola	2.9	2.8	4.1	4.0	4.3	4.6	5.0	5.4	5.2	4.5	3.6	2.4	48.8
Mobile	2.6	2.5	2.8	3.5	3.7	4.0	4.1	4.6	4.6	4.1	3.4	2.2	42.1
Montgomery	3.5	3.3	5.1	6.5	5.9	5.8	4.3	4.5	5.7	4.6	4.3	3.1	56.6
Vicksburg	2.1	2.5	3.6	5.1	5.7	4.8	4.0	5.0	4.7	3.4	4.0	2.2	47.1
New Orleans	2.8	2.8	4.1	3.8	4.2	4.1	4.1	4.3	4.4	4.6	3.7	2.5	45.4
Western Gulf States.													
Shreveport	1.6	2.1	3.0	4.8	4.9	4.2	4.9	5.2	5.0	4.1	3.4	2.4	45.6
Fort Smith	2.2	2.7	3.5	5.3	4.4	4.6	5.6	4.6	4.7	5.9	3.9	2.2	49.6
Little Rock	2.1	2.8	3.5	5.5	4.8	4.1	5.4	5.9	5.8	5.2	4.3	2.3	51.7
Corpus Christi	1.4	1.6	3.3	3.0	3.2	3.9	4.4	4.3	4.3	4.1	3.0	2.3	38.8
Galveston	1.6	2.8	3.2	2.9	4.3	4.2	5.3	5.2	5.2	4.7	4.2	2.4	46.0
Palestine	2.1	3.0	3.3	4.2	4.3	4.5	5.8	4.6	4.8	4.4	4.0	2.1	47.1
San Antonio	2.4	3.3	4.1	3.8	4.0	4.5	6.6	5.8	5.2	5.4	4.2	3.1	52.4
Rio Grande Valley.													
Rio Grande City	2.7	3.5	3.5	3.6	4.5	4.6	6.9	7.0	5.2	4.9	3.6	3.1	53.1
Brownsville	1.8	2.6	2.9	3.0	3.5	3.9	4.0	4.1	3.3	3.0	2.6	2.3	37.0
Ohio Val. & Tennessee.													
Chattanooga	2.0	3.3	3.3	5.3	3.7	4.3	4.3	5.0	5.4	4.0	3.9	1.9	46.4
Knoxville	2.4	2.6	3.4	5.0	3.5	4.2	4.9	5.0	4.9	4.1	3.8	2.1	45.9
Memphis	2.1	2.3	3.1	5.9	5.3	4.8	4.9	5.4	5.5	4.2	4.1	2.4	50.0
Nashville	1.9	2.1	3.2	5.9	5.0	5.1	5.5	6.3	5.9	4.0	3.3	1.9	50.1
Louisville	1.7	2.1	2.8	5.6	5.4	5.8	6.8	7.4	6.4	4.9	3.8	2.1	54.8
Ind anapolis	1.3	1.4	2.2	4.6	4.8	5.7	7.7	6.9	5.2	4.1	3.1	1.6	48.6
Cincinnati	1.8	1.8	2.6	4.9	5.2	6.4	6.5	6.6	6.1	4.7	3.3	2.1	52.0
Columbus	1.6	2.0	2.3	4.5	4.8	5.8	6.9	6.4	5.1	4.0	2.6	1.8	47.8
Pittsburg	1.4	1.9	2.2	3.8	4.2	5.4	6.6	5.6	4.9	3.4	2.8	2.3	44.5
Lower lake region.													
Buffalo	0.8	1.1	1.3	2.2	3.3	3.9	4.9	5.2	3.9	2.8	1.9	1.6	32.9
Oswego	0.6	1.0	1.1	2.2	2.8	3.8	3.9	4.0	3.6	2.7	2.2	1.0	28.9
Rochester	0.5	1.1	0.9	2.6	3.8	4.9	4.6	4.1	3.8	2.6	2.2	1.3	32.4
Erie	1.0	1.4	1.4	2.7	3.7	4.6	5.5	4.8	3.1	2.5	1.9	1.2	33.8
Cleveland	1.1	1.4	1.5	2.9	3.3	4.4	5.2	4.9	3.8	3.4	2.4	1.4	35.7
Sandusky	0.8	1.4	1.5	3.2	3.7	4.6	5.4	5.4	3.7	3.4	2.2	1.3	36.6
Toledo	0.9	1.1	1.5	3.5	3.8	4.6	6.0	6.4	3.7	3.4	2.4	1.3	38.6
Detroit	0.8	1.1	1.6	3.0	4.1	4.8	5.9	5.2	3.4	2.8	2.0	1.3	36.0
Upper lake region.													
Alpena	0.7	0.6	0.9	1.6	2.1	3.6	3.8	3.7	2.8	2.2	1.5	0.8	24.3
Grand Haven	0.5	0.7	1.3	2.6	3.1	3.8	4.7	3.8	2.7	2.6	1.7	1.1	28.6
Lansing	0.6	1.2	1.4	2.7	2.8	4.0	4.3	3.9	2.4	1.9	1.4	1.0	27.6
Marquette	0.8	0.8	0.9	1.7	2.4	3.3	3.4	3.3	3.1	2.2	1.3	1.3	24.5
Port Huron	0.6	1.0	1.1	2.6	3.0	3.8	4.6	4.2	3.2	2.5	1.7	1.0	29.3
Chicago	1.0	1.2	1.8	3.2	3.3	4.8	5.4	5.3	4.1	3.2	2.3	1.2	36.8
Milwaukee	0.5	1.0	1.1	2.4	2.6	3.8	4.8	3.7	3.4	2.9	1.9	0.9	29.0
Green Bay	0.5	0.6	0.8	1.7	2.5	4.1	5.6	4.2	3.0	2.4	1.9	0.9	28.2
Duluth	0.5	0.5	0.6	1.5	2.4	2.5	3.9	3.4	3.0	2.5	1.2	1.0	23.0
Extreme northwest.													
Moorhead	0.2	1.4	0.5	2.1	3.6	3.8	3.7	3.3	3.5	2.4	1.3	0.5	26.3
Saint Vincent	0.3	0.3	0.5	1.8	3.8	3.9	3.1	2.6	2.6	2.0	0.9	0.3	22.1
Bismarck	0.4	0.6	0.6	3.0	4.3	4.1	5.6	4.2	4.0	2.6	1.2	0.4	31.0
Fort Buford	1.4	0.7	0.6	3.0	4.7	5.0	6.2	4.9	4.8	3.0	1.7	0.5	35.5
Fort Totten	0.2	0.3	0.4	2.2	4.6	3.8	4.2	3.7	3.7	2.3	1.4	0.4	27.2
Upper Mississippi Val.													
Saint Paul	0.7	0.7	2.2	2.0	2.3	4.1	5.0	3.7	2.8	2.4	1.5	0.7	28.1
La Crosse	0.4	1.2	1.4	3.3	3.5	4.4	5.4	4.7	3.0	3.0	1.8	0.8	32.9
Davenport	0.5	1.0	1.8	3.8	3.4	4.6	6.9	6.2	4.4	3.0	2.3	1.1	39.0
Des Moines	0.6	1.0	1.5	3.7	3.1	4.2	6.6	4.7	4.1	3.3	2.3	0.9	36.0
Dubuque	0.7	1.0	1.4	2.2	2.9	4.2	6.2	4.8	3.3	2.8	1.8	0.9	33.2
Keokuk	0.8	1.1	2.1	4.2	3.7	4.3	7.0	6.8	5.0	3.8	2.9	1.2	42.9
Cairo	1.6	2.1	2.9	5.8	4.4	4.3	5.6	6.5	5.1	4.5	3.8	2.3	48.9
Springfield, Ill	0.8	1.1	2.0	4.6	3.8	4.3	5.4	6.5	4.5	3.5	2.9	1.4	40.8
Saint Louis	1.3	1.6	2.5	5.5	4.7	5.0	7.5	8.0	5.9	4.9	3.9	1.4	52.2
Missouri Valley.													
Lamar	1.1	1.6	2.4	4.4	3.8	4.0	6.0	4.6	3.7	3.6	2.9	1.5	39.6
Springfield, Mo	1.1	1.7	2.4	5.0	4.8	4.0	5.0	3.4	3.4	3.5	3.1	1.4	38.3
Leavenworth	0.9	1.5	2.3	4.6	4.5	5.0	6.3	4.5	4.0	3.9	2.7	1.4	41.6
Topeka	1.1	1.2	2.0	4.0	4.1	4.1	6.3	3.5	3.2	3.0	2.2	1.4	36.1
Omaha	0.8	1.5	1.4	4.4	3.8	5.2	6.2	5.2	4.3	4.3	3.0	1.4	41.7

TABLE III.—*Depth of evaporation, in inches, at Signal Service stations, &c.*—Continued.

Stations and districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Missouri Valley.													
Crete	0.7	1.1	1.2	3.5	3.3	4.5	5.6	4.7	3.8	3.6	2.4	1.1	35.5
Valentine	1.2	1.6	1.8	5.0	3.2	5.3	6.9	5.0	5.2	3.8	3.3	1.5	43.8
Fort Sully	0.6	0.9	1.3	4.4	4.1	5.2	7.7	4.9	5.7	3.6	2.8	0.7	41.9
Huron	0.3	0.7	0.8	3.7	3.7	4.1	5.7	4.2	4.1	3.1	2.4	0.7	33.0
Yankton	0.4	1.4	1.2	3.3	3.1	4.4	4.6	3.7	2.9	3.0	2.2	0.8	31.0
Northern slope.													
Fort Assiniboine	0.8	1.2	1.2	3.8	4.1	4.2	6.8	5.5	4.8	3.5	2.5	1.1	39.5
Fort Custer	0.6	1.5	1.3	5.4	6.8	4.9	9.6	8.0	6.1	3.4	2.9	1.5	52.0
Fort Maginnis	1.1	1.4	1.1	3.3	3.2	4.6	6.8	4.6	3.8	2.8	2.0	1.1	35.8
Helena	1.1	3.6	2.1	6.1	4.3	5.5	7.2	7.7	6.4	4.3	3.0	2.1	53.4
Poplar River	0.4	0.8	0.8	2.7	4.9	5.7	6.0	4.8	4.4	2.5	1.7	0.7	35.4
Cheyenne	3.3	5.7	4.0	8.2	5.2	10.4	8.0	7.7	8.6	5.8	6.1	3.5	76.5
North Platte	0.8	1.8	1.8	5.4	3.9	6.9	6.0	4.8	3.7	2.8	2.3	1.1	41.3
Middle slope.													
Colorado Springs	3.0	3.3	4.1	6.7	5.6	4.3	6.7	7.2	6.8	4.6	4.2	2.9	59.4
Denver	2.8	3.7	3.5	7.6	5.8	10.5	8.3	8.5	6.1	4.9	4.2	3.1	69.0
Pike's Peak	2.1	1.3	1.5	2.1	1.8	1.9	3.0	4.0	3.0	2.3	2.8	1.0	26.8
Concordia	1.3	2.8	1.8	4.8	4.3	5.7	7.3	5.2	4.3	4.5	3.4	1.8	47.2
Dodge City	1.4	2.4	2.8	4.1	4.6	7.4	8.3	6.6	5.5	5.2	4.2	2.1	54.6
Fort Elliott	1.3	1.9	3.2	5.1	5.4	8.2	7.6	6.2	5.4	4.7	4.2	2.2	55.4
Southern slope.													
Fort Sill	1.6	2.0	2.6	3.8	4.0	4.4	4.8	7.5	5.1	4.2	4.1	2.0	46.1
Abilene	1.8	1.7	3.1	4.2	5.0	5.8	9.5	7.5	6.2	4.5	3.4	1.7	54.4
Fort Davis	5.4	5.7	6.7	8.5	11.0	12.0	11.4	9.0	5.9	5.2	5.7	4.9	96.4
Fort Stanton	3.9	3.9	5.2	7.3	9.5	10.9	9.4	11.6	3.9	4.0	3.6	3.8	76.0
Southern plateau.													
El Paso	4.0	3.9	6.0	8.4	10.7	13.6	9.4	7.7	5.6	5.2	4.6	2.9	82.0
Santa Fé	3.0	3.4	4.2	6.8	8.8	12.9	9.2	9.8	6.6	6.7	5.7	2.7	79.8
Fort Apache	2.6	3.0	3.6	6.8	9.4	9.1	7.1	6.7	5.3	5.2	4.1	2.6	65.5
Fort Grant	5.2	4.8	6.4	9.2	10.2	13.8	12.4	10.5	9.0	7.9	7.2	4.6	101.2
Prescott	1.4	2.8	3.6	5.4	6.2	8.1	6.6	6.5	4.7	4.9	3.6	2.2	56.0
Yuma	4.4	5.2	6.6	9.6	9.6	12.6	11.0	10.2	8.2	8.2	5.5	4.6	95.7
Keeler	3.0	4.6	6.3	8.7	9.3	11.9	12.8	13.9	10.6	8.8	5.9	4.8	100.6
Middle plateau.													
Fort Bidwell	0.8	1.8	1.8	4.6	5.2	4.0	8.8	8.1	5.0	4.6	2.4	1.3	48.9
Winnemucca	0.9	2.8	6.2	9.1	9.3	10.1	11.5	12.0	9.9	6.6	3.7	1.8	83.9
Salt Lake City	1.8	2.7	3.6	7.2	6.9	8.9	9.2	10.7	9.6	6.5	5.0	2.3	74.4
Montrose	1.8	2.7	3.7	6.2	7.0	11.1	10.2	8.3	6.9	5.2	3.4	2.0	68.3
Fort Bridger	1.6	2.5	2.7	4.3	4.3	6.5	7.7	6.8	5.6	4.2	5.2	4.7	56.1
Northern plateau.													
Boisé City	1.6	2.5	3.8	6.1	6.5	6.6	10.0	9.2	7.4	5.2	3.2	1.8	63.9
Spokane Falls	0.7	1.7	2.7	4.4	5.4	4.4	7.7	6.4	3.8	2.5	1.7	1.4	42.8
Walla Walla	1.1	2.9	3.6	6.2	7.7	5.7	9.9	7.9	5.1	3.4	1.8	2.4	57.7
North Pacific coast.													
Fort Canby	1.2	1.1	1.8	2.1	2.8	2.3	1.8	2.9	1.8	1.8	1.5	0.9	21.1
Olympia	1.3	1.2	1.8	2.5	4.1	3.3	3.2	3.1	2.4	1.5	1.3	1.1	26.8
Port Angeles	1.0	0.9	1.8	1.8	2.5	2.1	2.1	1.8	1.5	1.2	1.3	1.1	19.1
Tatoosh Island	1.2	1.1	1.8	1.4	1.8	1.8	1.4	1.4	1.4	1.6	1.8	1.4	18.1
Astoria	1.1	1.0	1.6	2.1	3.0	2.7	3.0	2.9	2.6	2.3	1.8	1.2	25.3
Portland	0.9	1.1	2.4	3.4	5.0	3.2	5.4	4.2	3.4	2.7	1.8	1.2	34.7
Roseburg	1.2	1.6	2.7	3.9	4.7	3.5	5.4	4.7	5.0	3.2	1.7	1.6	39.2
Middle Pacific coast.													
Red Bluff	3.0	4.6	5.4	6.1	7.0	6.9	11.0	10.7	10.1	10.5	5.9	3.6	84.8
Sacramento	1.8	3.1	3.7	4.3	4.2	5.6	5.9	5.6	6.5	7.3	3.9	2.4	54.3
San Francisco	2.7	2.7	3.3	3.1	2.8	3.1	2.4	2.5	3.3	5.0	2.8	3.0	36.7
South Pacific coast.													
Fresno	1.8	2.8	3.0	5.6	6.0	7.0	9.1	10.2	7.6	6.7	3.8	2.2	65.8
Los Angeles	2.3	2.0	2.8	3.4	3.0	3.8	3.2	3.5	3.1	4.1	3.0	3.c	37.2
San Diego	2.9	2.7	2.5	2.7	3.3	2.8	3.2	3.3	2.9	4.3	3.2	3.7	37.5

Form 106 F.

Chart VI. Lines of Equal Annual Depth of Evaporation, in inches. Based on observations from July, 1887, to June, 1888, inclusive.